C. Bluffs

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(from Oxford)

COOPERATIVE SEDIMENTATION SURVEY OF LAKE GUAYABAL

FOR

PUERTO RICO WATER RESOURCES AUTHORITY

and

BUREAU OF RECLAMATION

UNITED STATES DEPARTMENT OF THE INTERIOR

by

J. Roger McHenry, Research Soil Scientist

and

Paul H. Hawks, Geologist

USDA Sedimentation Laboratory

Soil and Water Conservation Research Division

AGRICULTURAL RESEARCH SERVICE

UNITED STATES DEPARTMENT OF AGRICULTURE

Oxford, Mississippi

January, 1965
(2nd run)

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UNITED STATES DEPARTMENT OF AGRICULTURE
AGRICULTURAL RESEARCH SERVICE
SOIL AND WATER CONSERVATION RESEARCH DIVISION
P. O. Box 30
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USDA Sedimentation Laboratory May 21, 1965

To: Administrator
Agricultural Research Service

Through: Dr. C. H. Wadleigh, Director
Soil and Water Conservation
Research Division

From: Donald A. Parsons, Director
USDA Sedimentation Laboratory

This report describes the work done last September and October in a cooperative effort of the USDA Sedimentation Laboratory and the Puerto Rico Water Resources Authority in the characterization of the densities, textures, and amounts of sediment deposits in Lake Guayabal, Puerto Rico.

The work was undertaken at the request of the Bureau of Reclamation, US Department of the Interior, as indicated by Mr. F. H. Spencer, Acting Administrator, in his letter to Mr. G. G. Stamm, Acting Assistant Commissioner, Bureau of Reclamation, dated June 24, 1964.

Donald A. Parsons

ACKNOWLEDGMENT

A number of people of the Puerto Rico Water Resources Authority were most cooperative and helpful to us in our work in Puerto Rico. The assistance, both technical and general, of Mr. Wilson Loubriel is most gratefully acknowledged. Mr. Jose Colon Pagan and Mr. Harold Toro put themselves and their organizations at our service. In doing so our work was able to proceed smoothly and swiftly. Personnel of the South Coast District, Messrs. Francisco Servera, Hernan Rodriguez, Ruben Vega and the staff at Juana Diaz, J. C. Santiago and Luis Torres among many, were extremely cooperative. We had only to ask and their help was given most graciously. We wish to acknowledge also the work of members of the USDA Sedimentation Laboratory staff who assisted in preparations for the work in Puerto Rico, in the analyses of the samples and of the data, and in the preparation of this report. The assignment in, and association with the people of, Puerto Rico was an enjoyable experience for us. We are pleased to have had this opportunity to contribute to the program of water utilization and to, ultimately, a better Puerto Rico.

INTRODUCTION

"Sedimentation problems inherent in the Western Division of the South Coast Irrigation District have increased to the point that action must be taken in the immediate future to prevent dissolution of the project due to inadequacy of available water supplies. The solution involves complex hydrological studies, land use considerations, an appraisal of economic values, and other technical considerations" (1). In writing thusly, Mr. Munson has summed up succinctly the problem besetting the South Coast Irrigation District, i.e., shortage of water.

Guayabal Dam, located just below the junction of the Jacaguas and the Toa Vaca Rivers, was constructed in 1913 to a height of 113 feet. This provided 9,580 acre-feet of water storage at the maximum water elevation of 325 feet. Sediment inflow was a problem from the start - a resurvey in 1939 showed a reduction of 3,887 acre-feet of storage capacity. Silt deposits at the upper face of the dam were interfering with operation of the irrigation outlet gate. During the forties some dredging occurred and in 1950 some 123 acre-feet of sediment was sluiced from the reservoir. Despite these efforts, by 1950, some 5,932 acre-feet of sediment had been trapped (this includes the estimated 502 acre-feet removed by the dredge and the sluicing operations).

In 1950 Guayabal Dam was raised 16 feet to a spillway elevation of 341 feet. This added some 5,526 acre-feet of storage; a total of 15,106 acre-feet. This was estimated to have been reduced to something like 8,000 acre-feet by 1961. It was estimated that the average silting rate of 3.60 acre-feet per square mile per year for the period 1914-1939 increased to 3.93 acre-feet per year per square mile for the years 1939-1950 (2).

The irrigated area of the South Coast Irrigation District is about 30,000 acres of which Guayabal Reservoir furnishes water for irrigation for 18,000 acres. With current sugar cane production methods optimum yields are obtained with 96 to 144 inches of water. In an area of 40 inches, or so, of rainfall the inadequacy of the Guayabal Reservoir is apparent. The average annual flow past Guayabal Reservoir has been 75,973 acre-feet which has been augmented by the Toro Negro diversion to a mean flow of 80,337 acre-feet per year. If all the flow were to be used in irrigation, which is not the case, 8 acre-feet would be available per acre for sugar cane irrigation (including 3.5 feet from rainfall). This is considered the minimal value for cane production. With the loss of nearly 50 percent of the original storage capacity in Guayabal present irrigation supplies are inadequate. Under the present soil management system of the Guayabal watershed (43.4 square miles) the annual decrease in storage capacity due to sedimentation approximates 160 acre-feet (2).

The 1964 estimates of Guayabal Reservoir storage capacity (Figure 1) did not include any measured points below the 312 foot elevation (near minimum water level for the year). In this portion of the storage pool refinements in measurement would increase the accuracy of the area-capacity curve for that portion below 312 feet and, if sediment density values were obtained, additional potential storage due to anticipated consolidation could be determined. In addition some indication as to the extent of consolidation of sediments in the deep pool would be useful in assessing economics of potential dredging operations.

On the basis of the reports of the Bureau of Reclamation to the Puerto Rico Water Resources Authority (1, 2) the Authority prepared to resurvey sediment conditions in Guayabal Reservoir. To this end the use of a gamma probe (radioisotope sediment probe) and operator was sought. The Bureau of Reclamation's gamma probe was not available. Therefore the Agricultural Research Service, specifically the Director of the USDA Sedimentation Laboratory, was contacted. After an exchange of correspondence, agreement was reached that the USDA Sedimentation Laboratory, Soil and Water Conservation Research Division, Agricultural Research Service, would make equipment and personnel available for the sediment survey in Puerto Rico.

This report details the results of the sediment survey conducted by personnel of the USDA Sedimentation Laboratory, Agricultural Research Service, working at Lake Guayabal, September-October, 1964, in cooperation with personnel of the Puerto Rico Water Resources Authority. The equipment used and the techniques employed are described and the resulting data discussed.

MATERIALS AND METHODS

Sediment Density. The gamma, or single, probe has been successfully used to measure *in situ* densities of reservoir sediments (3, 4). The gamma rays emitted from the radioactive source (radium-226 in the gamma probe) are subject to random scatter and reflection in the medium in which the probe is placed. Upon reflection to the probe their intensity, or flux, is detected by Geiger-Muller tubes within the probe. Direct transmission of the gamma rays from source to the detector tubes is prevented by a lead shield (see Figure 2). The scattered and reflected rays are subjected to attenuation. This attenuation is proportional to the density of the medium. Calibration curves are constructed (4) relating the observed gamma-ray flux intensities to the known wet density of a prepared sediment.

Two gamma probes were used in the Lake Guayabal survey. The gamma probes were made by Technical Operations, Inc., of Burlington, Massachusetts. The USDA Sedimentation Laboratory had used one of the gamma probes since 1958. The second was ordered, and delivered, after negotiations with the Puerto Rico Water Resources Authroity were initiated. Probe specifications and performance were equal although the cables, and necessarily the connectors, were different.

In making field measurements with the gamma probe, a raft has proved most effective. Such a raft, with gamma probe and accessory equipment and operating personnel, is shown in Figure 3. Aluminum extension pipes are fitted to the gamma probe to provide positive control of the probe (Figure 4). The gamma probe, extension tubing, and connecting power and signal cable are lowered through the well on the raft (Figure 4) into the water to the underlying sediment controlled by a reel and cable (Figure 3). An adjustable clamp is used to support the aluminum sections (Figure 5). When the probe is in position in the sediment, measurements of the gamma radiation intensity are made. A scaler is used for this purpose (Figure 6). Normally 1-minute readings are taken. Upon completion of a measurement the probe is lowered, usually 6 or 12 inches, further into the sediment and another reading taken. This process is continued until the probe cannot be lowered further into the sediment, or the desired depth has been sampled. The observed readings are converted to density values utilizing conversion tables prepared from valid calibration curves (4).

The calibration employed expresses the results as wet, or total, density in grams per cubic centimeter. These results may be converted to pounds of dry soil per cubic foot assuming a specific gravity for the sediment. In practice we have assumed the specific gravity to be 2.65.

The gamma probe has a length of 22 inches. Experimental work (4) has shown the sensitive length to be some 18 inches (from the tip end). The center of this measured sphere of influence, i.e., 9 inches from the probe tip, is taken as the reporting depth. When a sediment density value is reported for a given depth, we are reporting that the center of the sensitive probe length, i.e., 9 inches from the tip, is at the recorded depth. The tip of the gamma probe is 9 inches deeper than the reported depth. The volume of sediment contributing to the density measurement is a spheroid with a length of 18 inches. However, it has been shown that 90 percent of the observed reading is a function of the density of a spheroid some 12 inches in length (4).

Depth Measurements. A contour map of Lake Guayabal topography was made in 1964. This, in part, was done by means of aerial photography.[1/] The lake was photographed in March 1964. The map has a contour interval of 3 feet from elevation 315 to elevation 351. The 312 contour was surveyed by transit in August 1964.[2/] At the time of this survey the water elevation was approximately 312.

A fathometer survey was made by the authors in September 1964 to complete the 1964 contour map. The fathometer (Figure 7) is a sonic device for measuring water depth based on the travel time of sound waves which are reflected from the lake bottom to the instrument.

Five fathometer ranges (Figure 8) were run on Lake Guayabal. The ends of the ranges were established by use of a transit. Fathometer readings were taken from a motor boat traversing the range at a slow, constant speed. Readings were made at 15-second intervals timed with a stopwatch. The fathometer readings were spaced about 33 feet apart.

1/ Mark Hurd Aerial Surveys, Inc.

2/ Survey made by Mr. Ruben Vega, Supervisor, Western Section, South Coast Irrigation District.

From this survey, correlated with measured depths at sampling sites and previous contours where possible, the 1964 contour map of Lake Guayabal was completed. Contours were drawn from elevations 274 to 312 at two-foot vertical intervals.

All contours from elevation 274 to 341 were planimetered and the stage-area information was tabulated. Stage capacities were computed using two methods (5). The first method used was the planimetering of areas under a stage-area curve (Figure 1). The second computation was made by using the prismoidal formula (Table 1):

$$C = \frac{L}{3} (A + \sqrt{AB} + B)$$

where

L = the contour interval in feet
A = the area of higher contour in acres
B = the area of lower contour in acres
C = the capacity between areas A and B in acre feet.

Both methods agreed closely at all stages.

Mechanical Analysis. Mechanical analyses were performed on grab samples of sediment taken at designated points. The pipet method of Kilmer and Alexander (6), with some modifications, was employed. This work was done by the Sediment Analysis Laboratory under the direction of Mr. B. R. Carroll, USDA Sedimentation Laboratory.

SEDIMENT MEASUREMENTS

The increase of trapped sediment with time is shown graphically in Figures 9, 10, and 11; topographic contour maps of Lake Guayabal based on 1908, 1950, and 1964 data. The original contours, 1908, were based on a map by the U. S. Geological Survey. The contour interval was 10 feet. In 1950, at the time the dam was raised, the reservoir was dry for a number of months and a complete contour map was prepared. The contour interval was 15 feet in 1950. The 1964 map shows two-foot contours from elevation 276 to 312 and three-foot contours above elevation 312.

The data from the 1964 contour map (Figure 11) have been combined with previously reported stage-area and stage-capacity data (2). This information is summarized in Figure 1. The data obtained in the gamma probe sedimentation survey permitted more precise stage-area and stage-capacity curves to be constructed. The increase in computed storage capacity is due to measurements in the deeper pool. Here sedimentation had not progressed as far as previous estimates had indicated. The calculated average silting rate (2) is also found to have decreased.

Years	Average Annual Silting Rate (acre-feet per square mile)
1914 - 39	3.60
1939 - 50	3.93
1914 - 50 (av.)	3.69
1950 - 1964	3.07

Measurements of sediment density were made at selected sites. These sites are shown on the accompanying sketch map of Lake Guayabal (Figure 12). Twenty-seven positions are reported. The maximum (wet) density measured in the lower pool was 1.626 g./cc.; 52.5 feet below the water surface, 7 feet below the sediment surface; at position four. A high density of 1.940 g./cc. was obtained at site 27, in the Toa Vaca River delta. This high density is associated with the sands and gravels of the delta deposits (Table 2).

Sediment depths of practically zero to a maximum of 9 feet were measured. The sediment density probe normally cannot be forced into sediment previously dried nor into the original soil material. This limitation of the gamma probe is recognized (3, 4). The results, we believe, indicate that the sediment depths measured are for those sediments accumulated since 1950, where water has been maintained, or since the spring of 1964 where the area was dry. In the area of greatest interest, i.e., below the 312 contour, the data are most reliable.

In the deep pool area, below the 312 contour, sediment at a depth of 50 to 60 feet (total depth of water and sediment) is found to have a density as great as 1.50 to 1.57. On the assumption that consolidation to a density of about 1.55 (55 pounds per cubic foot of dry material) may occur with time, the ultimate depths of sediment at the various depths within the deep pool can be estimated.

In the deep pool area, below the 300-foot contour, such a compaction would lower the sediment surface by 1.5 to 2.0 feet. This would in time increase the reservoir capacity by something like 200 acre-feet. This potential increase in the capacity of Guayabal Reservoir is real but has little effect on estimates of the ultimate useful life of the reservoir or on increasing irrigation storage capacity in the near future.

Borland and Miller (7, 8) have a prediction equation for the computation of reservoir sediment campaction. Applying this equation to the data for the Lake Guayabal (using the mechanical analyses of the grab samples as typical of incoming sediment) a 14-year period of consolidation would change the surface materials to a density similar to that in the lower portion of the measured profile, i.e., about 50 to 55 pounds per cubic foot. The longtime (50-year) predicted consolidation value would be from 55 to 60 pounds per cubic foot.

In Figure 8 the location of the ranges for taking fathometer depth readings and the location of the samples for mechanical analyses are shown. Table 2 summarizes the mechanical analyses of these samples. In general, the closer to the dam the greater is the percentage of fine material in the sediment. Insufficient data are available to identify or characterize any differences between the sediment loads of the Toa Vaca and the Jacaguas Rivers.

Sediment density data obtained with the gamma probe are presented in Table 3. As given, at the depth noted, the tip of the probe is 9 inches deeper. Site 21 is located at the deepest point in the reservoir sampled and the greatest depth of sediment was found at Site 19.

DISCUSSION

Two problems pertinent to the Lake Guayabal sedimentation problem were (1) the form of the stage-area and stage-capacity curves and (2) the location of sediments of various sized particles.

The stage-area and stage-capacity curves based on the early 1964 survey had no experimental basis below the 312 foot contour. Because of this the revised curves show considerably greater potential storage in the deep pool than had been previously estimated (Figure 1). The deep pool area, below 300 foot contour, contains about 45 percent of the computed deposited sediment (Figure 13). The major portion of the deposited sediment found in the reservoir is between the 275 and 318 foot contours (Figure 13).

The sediment density survey of 1964 does delineate closely the sediment elevations within the deep pool. The corresponding stage-area and stage-capacity curves were somewhat different than those previously estimated. However the changes, due to the overall small percentage of the deposited sediments in the deep pool, have no great effect on the overall conclusions to be drawn regarding the sedimentation status of Lake Guayabal.

The question as to where the sediments of various sized particles are to be found can be answered in part from consideration of Table 2 and Figures 8, 13, and 14. The change in depth of the reservoir with accumulation of sediment is plotted for the thalweg in Figure 14. The 1950 and 1964 thalweg slope values decreased considerably in the upper two-thirds of the reservoir (above the 5000 foot thalweg mark). In the lower reaches, less than 5000 feet from the dam, the slope of the thalweg has been maintained despite considerable deposition of sediment. As stated above this lower area contains about half of the overall sediment.

Likewise it can be pointed out that something less than 10 percent of the sediment is deposited in the upper reaches, greater than 8,000 to 10,000 feet. Only in these upper reaches of the two rivers are sands deposited (Table 2, Figure 8). Substantial silt and clay deposits are to be found between the 310 and 328 contours, corresponding to about 3500 to 7500 feet from the dam along the thalweg. These are at a considerable distance from any proposed damsite on the Toa Vaca River (1). The deposits in the upper half (distance-wise) of the reservoir approximate only 10 percent of the total, i.e., some 800 acre feet. This material occurs in

deposits as deep as 30 feet along the thalweg, but overall will average much less as seen in Figures 15a and 15b. In the lower pool (Figure 15a) the original thalweg and the adjoining valley floor are shown covered with sediment to a depth as much as 50 feet. The surface of this deposit is relatively uniform. Deposits since 1950 have conformed to this pattern. Much the same pattern of deposition is observed in the upper portion of the lake (Figure 15b). The present shallow nature of the upper part of Lake Guayabal is seen in cross-section D, Figure 15b. The deposit of sediment deposited between 1950 and 1964 is rather uniform. As described above, some 6 to 9 feet of sediment was deposited in this time interval. In the lower lake this sediment is still largely unconsolidated. In the upper portions of the lake it has been subjected to frequent drying and thus the sediment is partially consolidated.

Whether or not these deposits of sediment are sufficiently large and of a suitable nature for hydraulic fill purposes remains to be evaluated. The information presented here may be adequate for this evaluation; or again it may not be. The authors are not in a position to make this decision.

SUMMARY AND CONCLUSIONS

At the request of the Bureau of Reclamation, the USDA Sedimentation Laboratory sent a team of two persons to Puerto Rico to assist the Puerto Rico Water Resources Authority conduct a sedimentation survey of Lake Guayabal. Included in the work was a sediment density survey conducted with a gamma probe.

Guayabal Reservoir, constructed in 1913 and increased in capacity by dam heightening in 1950, provides irrigation water for the Western Division, South Coast Irrigation District. At full design capacity it was barely adequate for the job. Over the years sedimentation has greatly reduced its storage capacity. At present, with some 8,000 acre-feet of storage, it provides about one-half of the original total storage capacity. Sedimentation continues to reduce this already greatly reduced capacity.

This survey, conducted in 1964, shows the average mean sedimentation rate from 1950 to 1964 to be 3.07 acre-feet per square mile of the watershed. This is a reduction in rate from the 3.60 acre-feet calculated for the 1913-1939 period and the 3.93 acre-feet calculated for the 1939-1950 period. The cause, or causes, of this reduction in sedimentation rate is not clear. The 1964 survey revealed less sediment in the deep pool (below the 312 foot contour) than had been previously estimated. This change would reduce the computed sedimentation rate but not by the magnitude needed to account for all the decrease. Effectively some change in the land use pattern within the Lake Guayabal watershed has occurred in the last 10 to 15 years.

Wet densities of sediments, as measured with the gamma probe, were found to vary from 1.2 (g./cc.) to 1.6 in the deep pool area. Density values as high as 1.9 were recorded in the sands of the river delta. In general some increase in density occurred with depth of sediment. In the area of deepest sediment, with a clay content of 70 percent or more, an approximate maximum density of 1.55 was observed. Using this value as the probable consolidation density, an increase of some 200 acre-feet in storage capacity can be assumed with time. This value is of little real significance when it is compared with the present annual sedimentation inflow of approximately 130 to 150 acre-feet.

Measurement of density with the gamma probe was limited to those sediments not subject to drying. In the deep pool area,

below the 310 foot elevation, the sediments were 6 to 10 feet in depth. This depth of sediment is considered to be that deposited since 1950 when the entire reservoir was dry.

A major portion of the sediment has been deposited in the middle reaches of the reservoir (from 2500 to 7500 feet from the dam via thalweg). Materials deposited in the first 5000 feet thalweg distance from dam contain 60-70 percent and more of clay; the material in the middle reaches contains 30 percent or more of clay with very little sand. Only in the river delta areas is a significant amount of sand found. Less than 10 percent of the sediments (i.e., less than 800 acre-feet) are deposited in the reaches above the 5000 foot thalwegs of the Toa Vaca and Jacaguas Rivers.

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Table 1.--Stage Capacity* Computed for
Lake Guayabal, Puerto Rico, 1964

Elevation (ft.)	Area (acres)	Capacity (acre ft.)
274	.66	.2
276	2.35	3.0
278	3.51	8.9
280	4.65	17.0
282	6.06	27.7
284	6.86	40.6
286	9.06	56.4
288	12.70	78.1
290	16.73	107.4
292	21.31	145.4
294	27.93	194.5
296	36.34	258.6
298	43.99	338.8
300	51.96	434.4
302	57.47	543.8
304	64.19	665.4
306	72.17	801.9
308	77.46	951.5
310	85.50	1114.4
312	100.57	1300.2
315	126.17	1639.6
318	134.68	2030.8
321	158.17	2469.6
324	205.35	3013.4
327	238.45	3678.4
330	270.96	4442.0
333	293.44	5288.4
336	317.47	6204.5
339	347.72	7202.0
341	381.25	7930.5

*Stage Capacity was computed using the prismoidal formula

$$C = \frac{L}{3} (A + \sqrt{AB} + B)$$

where

L = contour interval
A = area in top contour
B = area in lower contour
C = capacity between areas A and B

Table 2.--Mechanical Analyses of Sediments,
Lake Guayabal, Puerto Rico, 1964

Sample No.	Particle Size, Diameter in Millimeters												Organic Matter
	7.93-4.000	4.000-2.000	2.000-1.000	1.000-.500	.500-.250	.250-.125	.125-.062	.062-.016	.016-.008	.008-.004	.004-.002	less than .002	
	Percentage by Weight												
1							0.2*	0.6	2.0	6.2	9.9	81.2	4.4
2							0.0*	1.0	1.3	9.0	14.7	74.0	2.3
3							0.0*	0.2	2.9	10.7	16.7	69.4	5.0
4							0.0*	2.4	9.9	19.4	15.6	52.7	7.5
5							0.0*	0.2	4.7	10.9	16.1	68.1	3.0
6							0.4*	34.2	17.2	10.6	7.7	30.0	6.5
7							1.3*	29.9	16.7	12.7	9.7	29.6	5.2
8							0.2*	13.9	22.3	19.7	11.3	32.6	2.2
9							2.7*	18.0	20.1	17.5	10.3	31.4	4.9
10	2.5	10.6	44.2	36.0	4.6	1.5	0.5**						
11	1.3	3.8	13.5	30.7	24.8	21.9	3.9**						
12			3.8	17.4	33.9	22.3	4.7	5.9	2.3	1.6	6.2	1.9	1.7

* Percent greater than .062 mm. in size.
** Percent less than .062 mm. in size.

Table 3.--Densities of Lake Guayabal Sediments Measured *in situ* with a Gamma Probe

Location	Depth of probe below water surface (to center of sensitive volume)	Measured (wet) Density
	feet	g./cc.
Site 1	32.75	1.11
	33.75	1.18
	34.75	1.26
	35.75	1.31
	36.75	1.35
	37.75	1.47
	38.75	1.47
	39.75	1.40
	40.75	1.49
	41.75	1.50
Sonar depth	31.5 feet	
Water elevation	340.85 feet	
Site 2	No significant penetration of probe in sediment.	
Site 3	41.75	1.00
	42.75	1.36
	43.75	1.48
	44.75	1.44
	45.75	1.46
Sonar depth	42 feet	
Water elevation	340.85 feet	
Site 4	44.75	1.00
	45.75	1.31
	46.75	1.38
	47.75	1.45
	48.75	1.57
	49.75	1.57
	50.75	1.54
	51.75	1.63
Sonar depth	44 feet	
Water elevation	340.85 feet	

Table 3.--Continued:

Site 5	46.75	1.00
	48.75	1.08
	49.75	1.33
	50.75	1.34
	51.75	1.41
	52.75	1.57
	53.75	1.55
Sonar depth	47.5 feet	
Water elevation	340.85 feet	
Site 6	54.75	1.05
	55.75	1.30
	56.75	1.35
	57.75	1.38
	58.75	1.39
	59.75	1.40
	60.75	1.51
	61.75	1.54
	62.75	1.55
Sonar depth	55 feet	
Water elevation	340.85 feet	
Site 7	59.75	1.00
	60.75	1.24
	61.75	1.32
	62.75	1.36
	63.75	1.36
	64.75	1.40
	65.75	1.45
	66.75	1.52
Sonar depth	60.0 feet	
Water elevation	340.80 feet	
Site 8	51.75	1.00
	52.75	1.06
	53.75	1.30
	54.75	1.36
	55.75	1.39
	56.75	1.46
	57.75	1.46
Sonar depth	52.0 feet	
Water elevation	340.80 feet	

Table 3.--Continued:

Site 9	50.75	1.00
	51.75	1.29
	52.75	1.35
	53.75	1.39
	54.75	1.39
	55.75	1.54
	56.75	1.54
	57.75	1.52
Sonar depth	54.0 feet	
Water elevation	340.80 feet	
Site 10	43.75	1.00
	44.75	1.28
	45.75	1.34
	46.75	1.42
	47.75	1.38
Sonar depth	44.0 feet	
Water elevation	340.80 feet	
Site 11	35.75	1.00
	36.75	1.27
	37.75	1.43
Sonar depth	36.0 feet	
Water elevation	340.80 feet	
Site 12	42.75	1.23
	43.75	1.34
	44.75	1.40
	45.75	1.45
	46.75	1.49
	47.75	1.46
	48.75	1.57
Sonar depth	43.0 feet	
Water elevation	340.60 feet	

Table 3.--Continued:

Site 13	36.75	1.00
	38.75	1.26
	39.75	1.33
	40.75	1.36
	41.75	1.47
Sonar depth	39.0 feet	
Water elevation	340.60 feet	
Site 14	44.75	1.00
	45.75	1.01
	46.75	1.27
	47.75	1.33
	48.75	1.37
	49.75	1.39
	50.75	1.48
	51.75	1.50
	52.75	1.48
	53.75	1.49
Sonar depth	45 feet	
Water elevation	340.58 feet	
Site 15	47.75	1.00
	48.75	1.06
	49.75	1.28
	50.75	1.35
	51.75	1.41
	52.75	1.41
	53.75	1.49
	54.75	1.55
	55.75	1.53
	56.75	1.52
Sonar depth	48.0 feet	
Water elevation	340.60 feet	

Table 3.--Continued:

Site 16	48.75	1.00
	49.75	1.03
	50.75	1.32
	51.75	1.35
	52.75	1.40
	53.75	1.42
	54.75	1.47
	55.75	1.52
	56.75	1.55
	57.25	1.50
Sonar depth	49 feet	
Water elevation	340.58 feet	
Site 17	49.75	1.00
	50.75	1.15
	51.75	1.33
	52.75	1.36
	53.75	1.41
	54.75	1.40
	55.75	1.48
	56.75	1.51
Sonar depth	49.0 feet	
Water elevation	340.60 feet	
Site 18	49.75	1.02
	50.75	1.00
	51.75	1.14
	52.75	1.31
	53.75	1.35
	54.75	1.42
	55.75	1.42
	56.75	1.51
	57.75	1.50
	58.75	1.53
	59.75	1.54
Sonar depth	51.0 feet	
Water elevation	340.60 feet	

Table 3.--Continued:

Site 19	53.75	1.03
	54.75	1.29
	55.75	1.34
	56.75	1.37
	57.75	1.40
	58.75	1.49
	59.75	1.47
	60.75	1.51
	61.75	1.52
	62.75	1.49
Sonar depth	54 feet	
Water elevation	340.88 feet	
Site 20	57.75	1.35
	58.75	1.41
	59.75	1.39
	60.75	1.41
	61.75	1.48
	62.75	1.54
	63.75	1.51
	64.25	1.51
Sonar depth	58.0 feet	
Water elevation	340.60 feet	
Site 21	64.75	1.29
	65.75	1.37
	66.75	1.36
	67.75	1.47
	68.75	1.47
	69.75	1.44
	70.75	1.48
	71.75	1.50
Sonar depth	65 feet	
Water elevation	340.88 feet	

Table 3.--Continued:

Site 22	51.75	1.00
	52.75	1.03
	53.75	1.28
	54.75	1.35
	55.75	1.38
	56.75	1.38
	57.75	1.50
	58.75	1.49
Sonar depth	52.0 feet	
Water elevation	340.60 feet	
Site 23	39.75	1.00
	40.75	1.32
	41.75	1.42
Sonar depth	41.0 feet	
Water elevation	340.60 feet	
Site 24	26.75	1.05
	27.75	1.50
	28.75	1.55
Sonar depth	27.0 feet	
Water elevation	340.60 feet	
Site 25	No significant penetration.	
Site 26 (Toa Vaca inlet)	11.25	1.00
	12.25	1.02
	12.75	1.36
Sonar depth	12.0 feet	
Water elevation	340.60 feet	

Table 3.--Continued:

Site 27 (Toa Vaca Channel)	5.75	1.00
	6.75	1.00
	7.75	1.49
	8.75*	1.94

*Coarse sand

Sonar depth	7.0 feet
Water elevation	340.60 feet

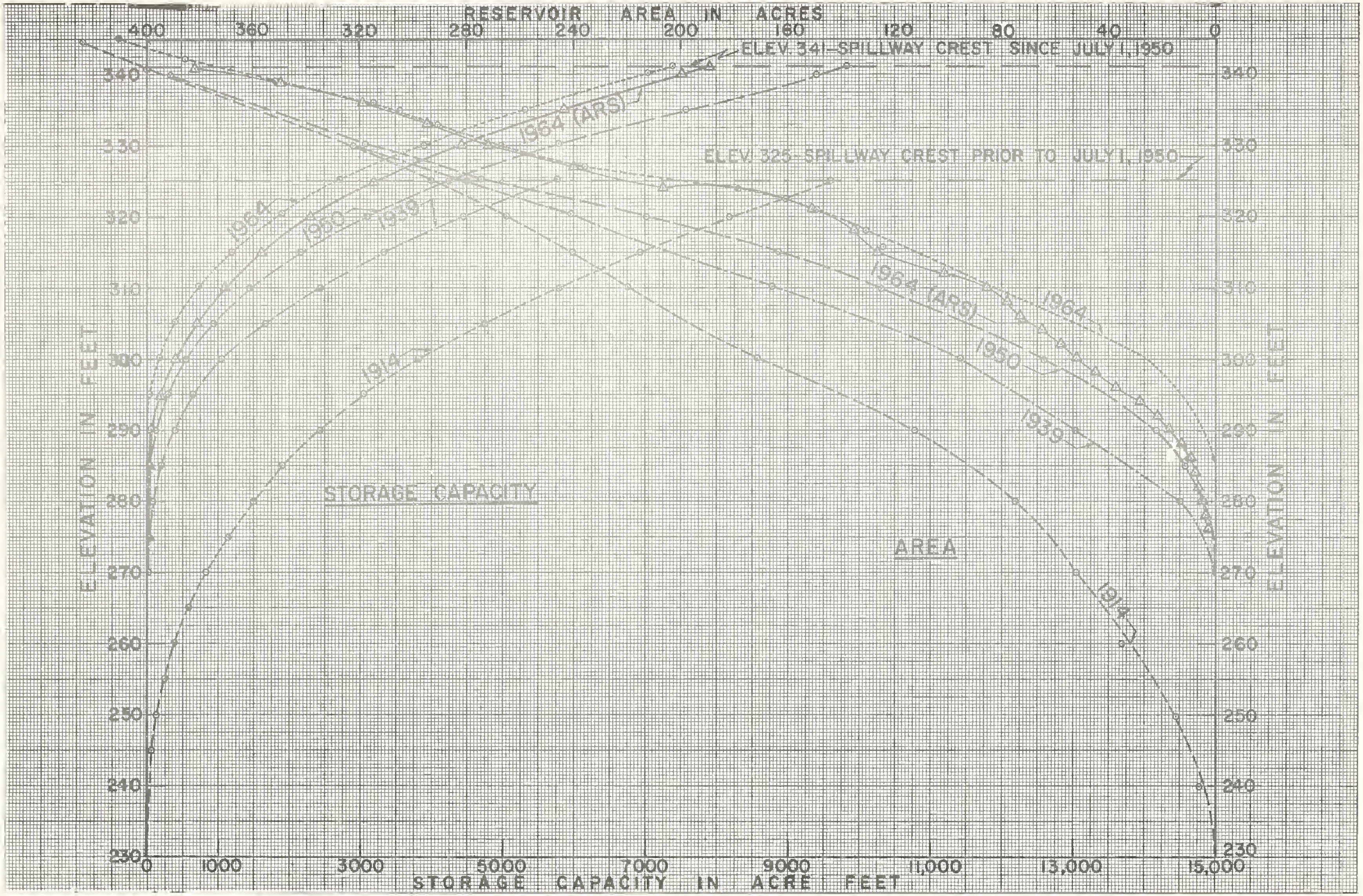


Figure 1.--Stage-area and stage-capacity curves computed for Lake Guayabal based on 1914, 1939, 1950, and two 1964 surveys.

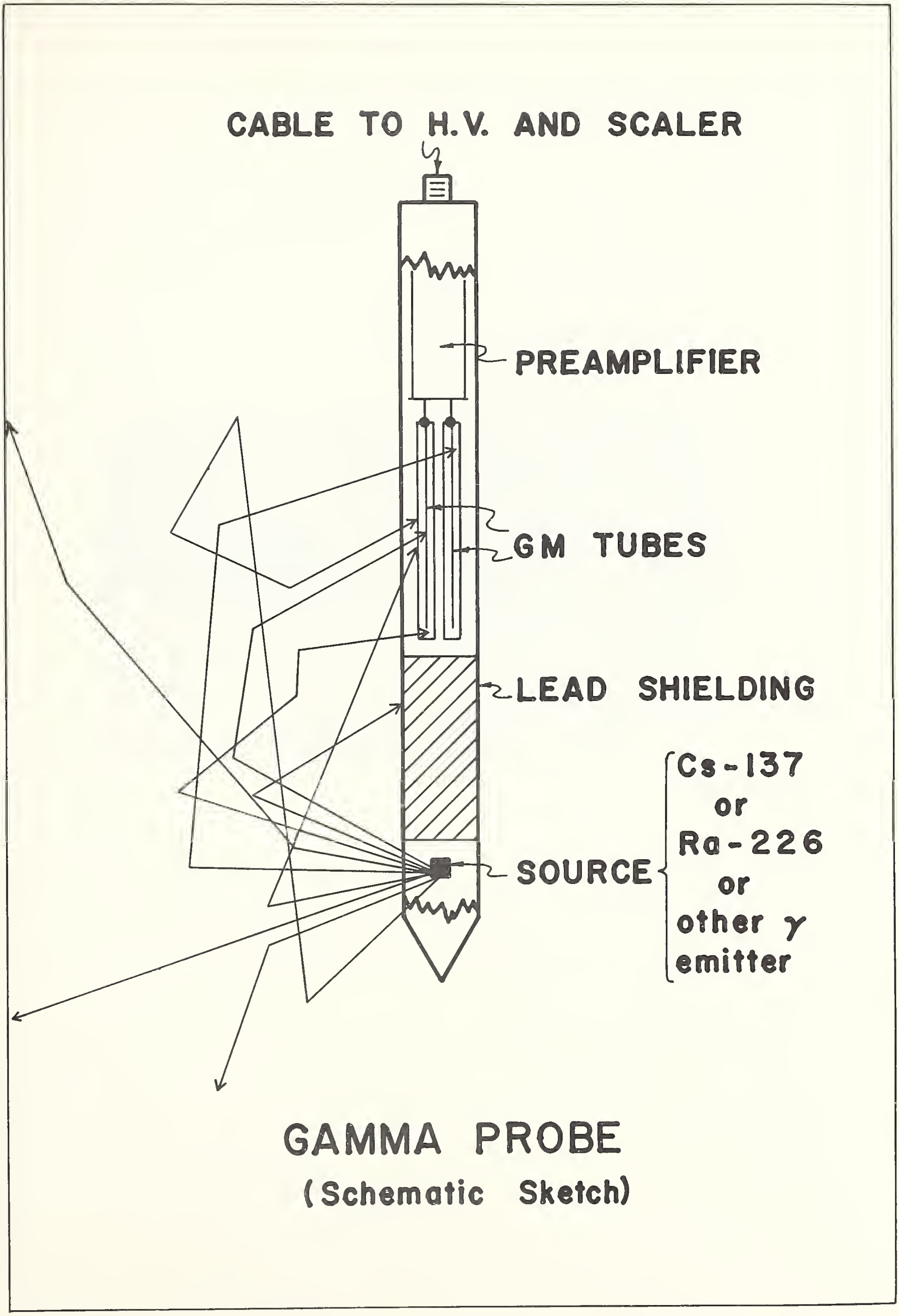


Figure 2.--Diagrammatic sketch of the Technical Operations gamma probe used in the sediment density survey of Lake Guayabal, 1964.

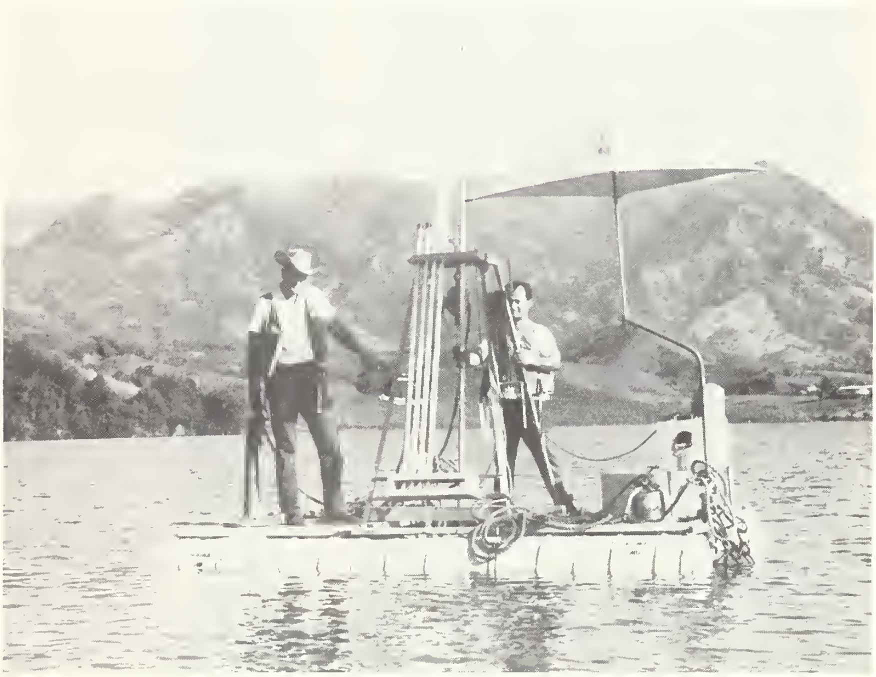


Figure 3.--USDA Sedimentation Laboratory Raft with equipment necessary for measuring sediment density with gamma probe. Man on the right is holding aluminum tubing supporting the radioactive probe. Note cable from tube to scaler (in box on extreme right of raft). The umbrella provides some protection from the elements to the electronic scaler.

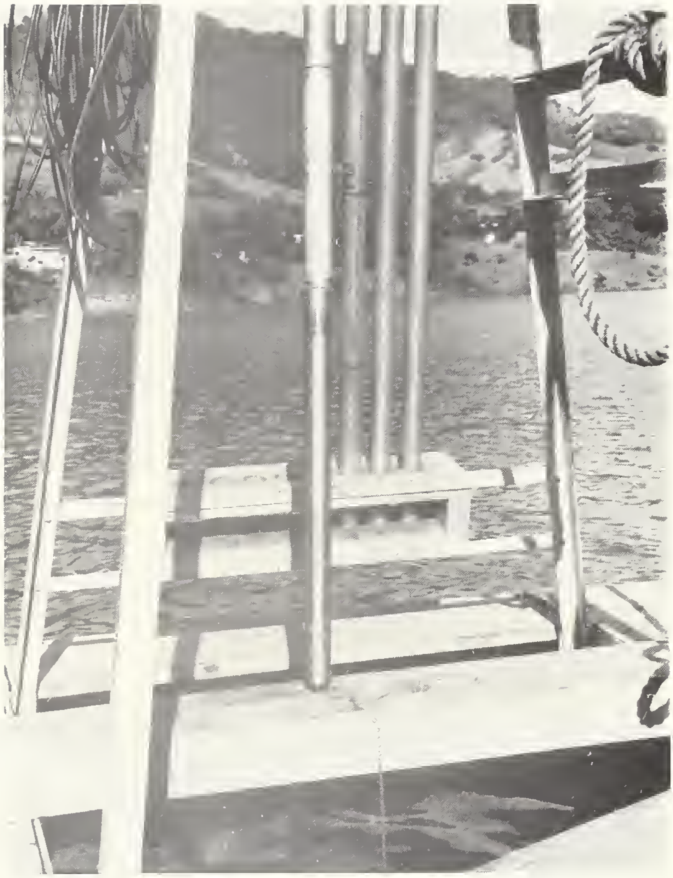


Figure 4. --A close-up view of the gamma probe. The radioactive source (radium-226) is located by the etched line on the lower end of the probe.

Figure 5.--Tube supporting probe and clamping device for holding tube and probe assembly. The wing-nuts permit quick clamping and unclamping at the tube.

Figure 6.--Operator taking a measurement. The radiation intensity "seen" by the GM tubes in the gamma probe is read out by this scaler. A stop watch is used to time the measurement period. Note the cable connecting the scaler to the probe.

Figure 7.--Making a depth measurement with the portable sonar device.
The transducer is held in the water by the man on the left.
The man to the right is reading the depth.

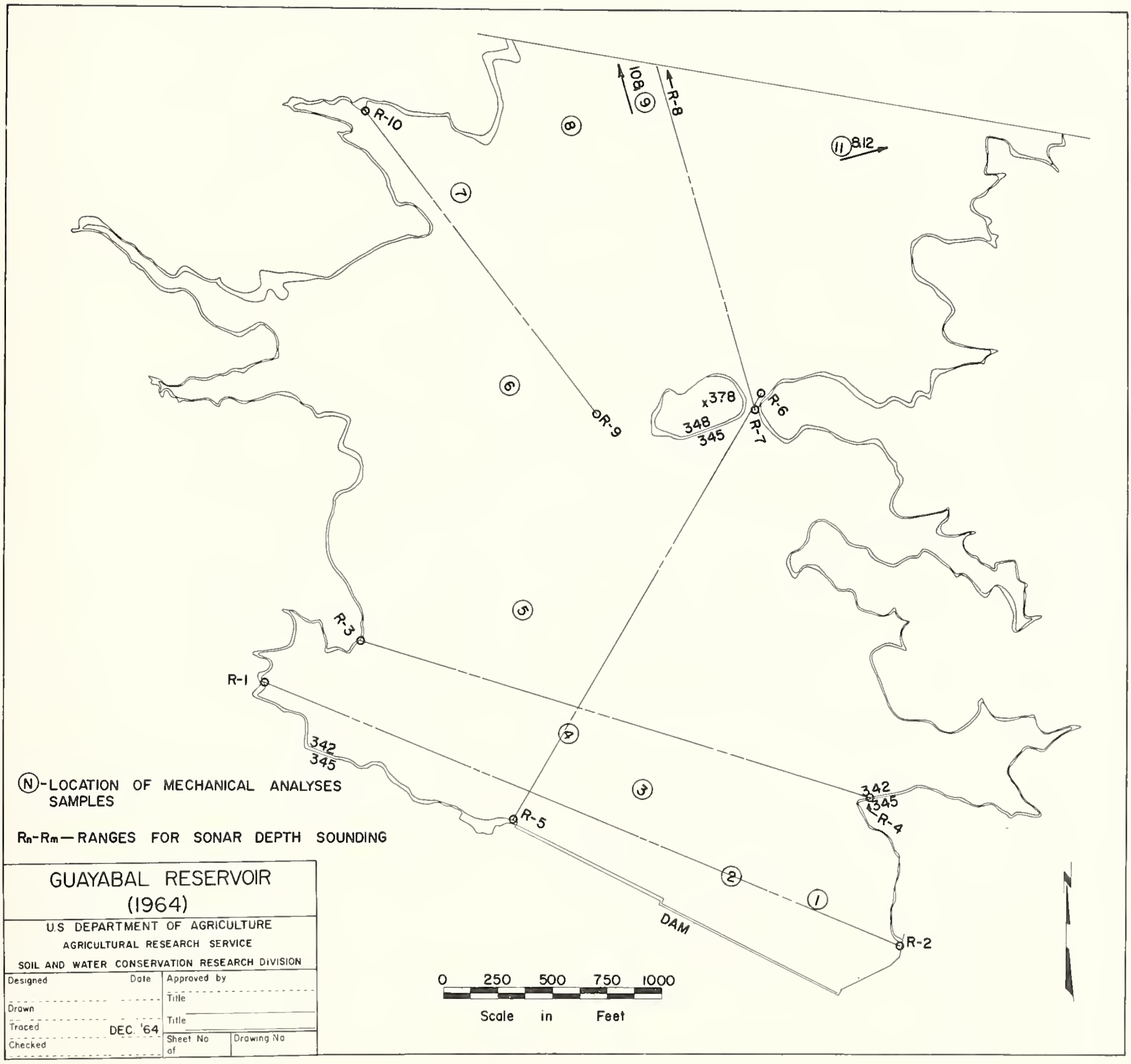


Figure 8.--Outline map of Lake Guayabal showing the location of mechanical analysis samples and ranges for depth sounding.

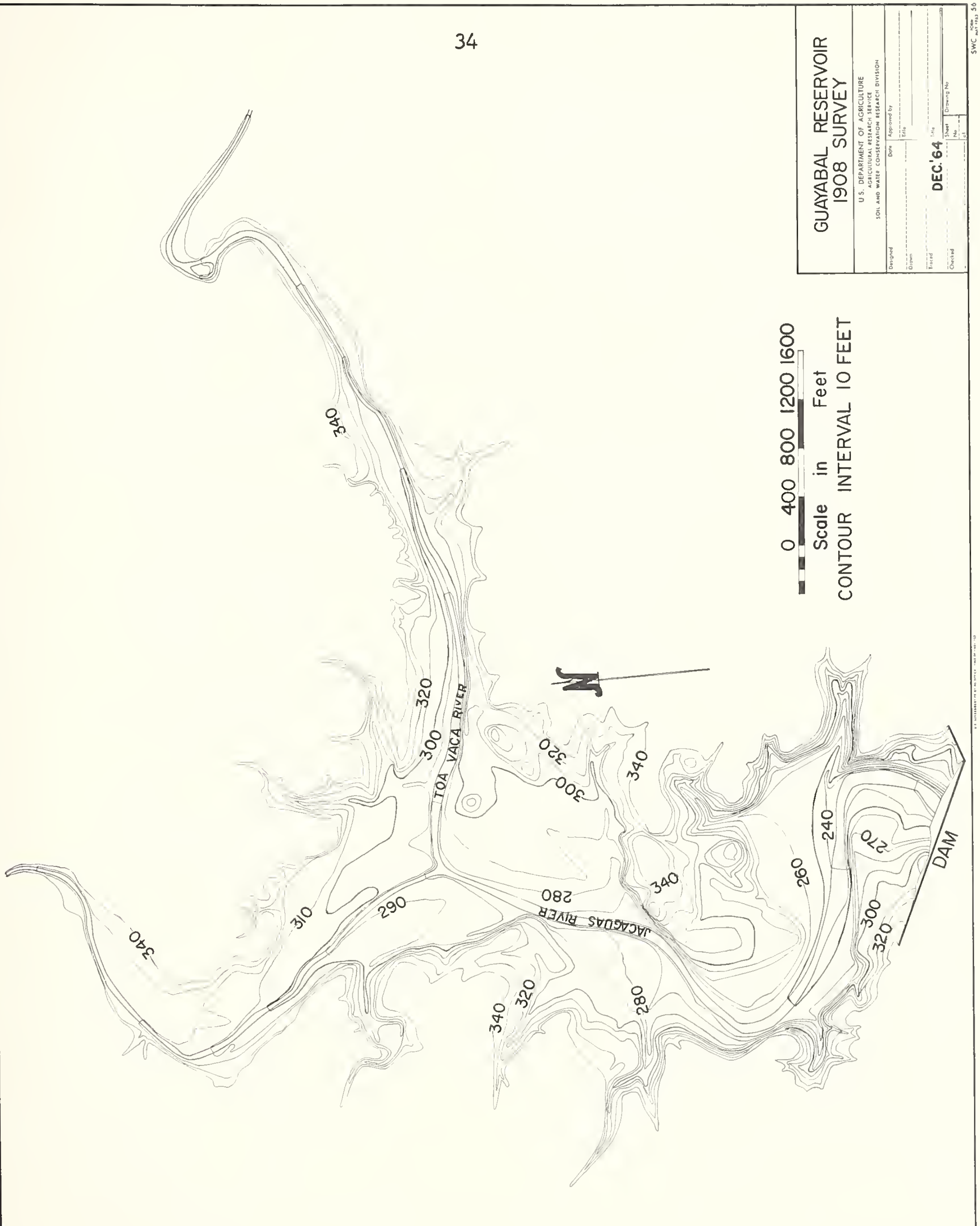


Figure 9.--Outline map of Lake Guayabal with contour lines based on a 1908 survey. These contours form the base on which sediment accumulation in the reservoir is calculated.

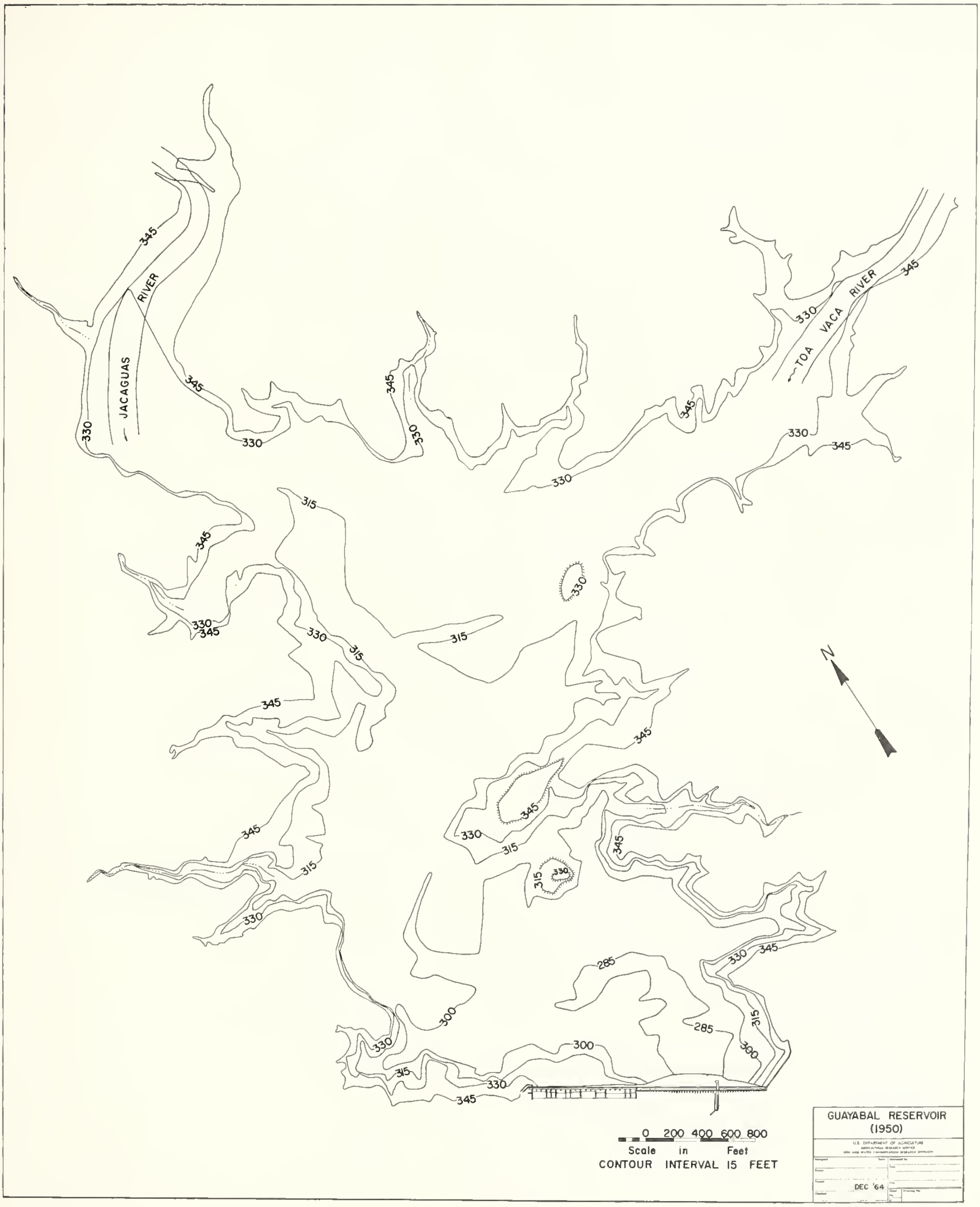


Figure 10.--Outline map of Lake Guayabal showing contour lines based on the 1950 survey. This survey was made at the time the dam was being heightened and the reservoir was dry.

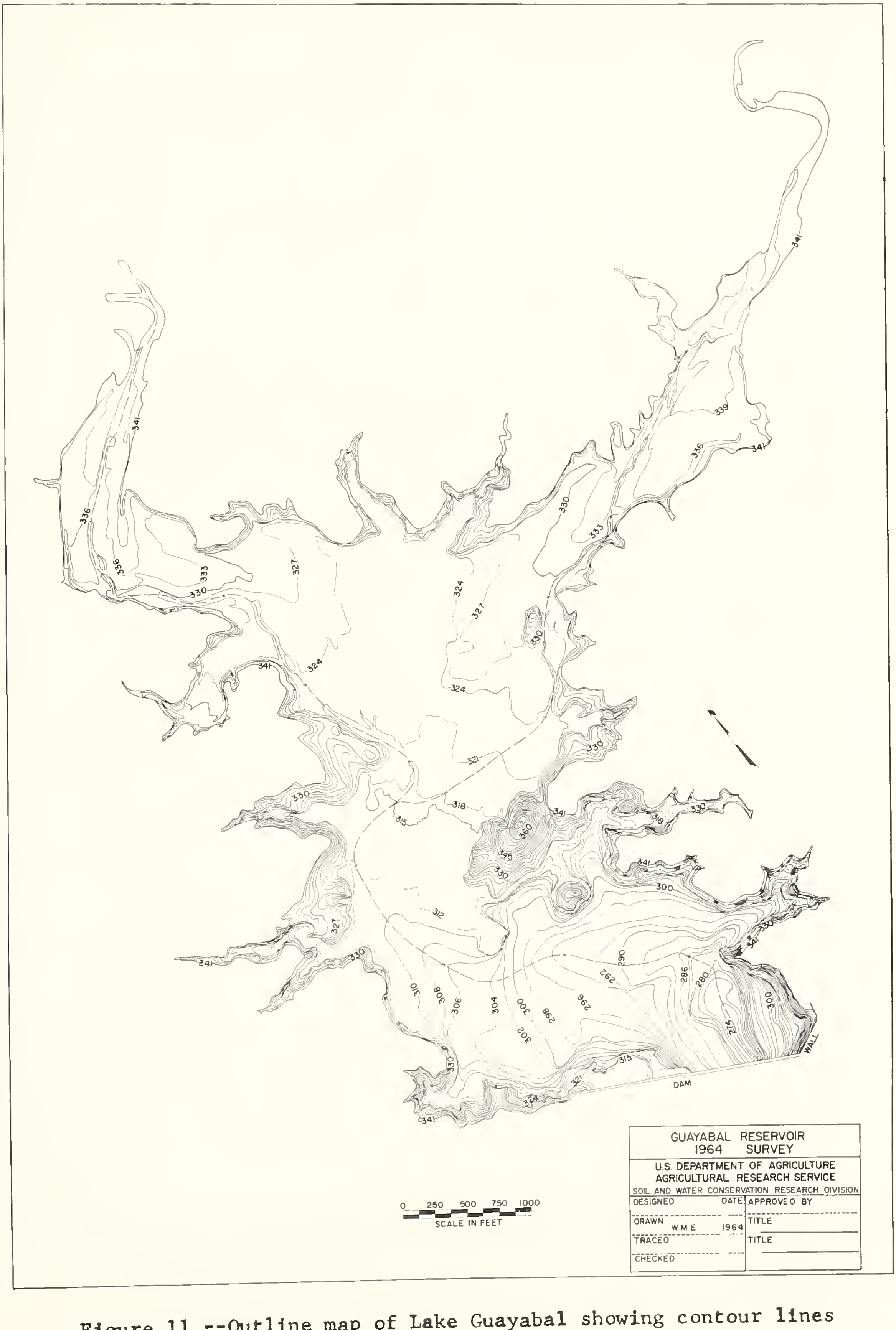


Figure 11.--Outline map of Lake Guayabal showing contour lines based on the 1964 sediment surveys.

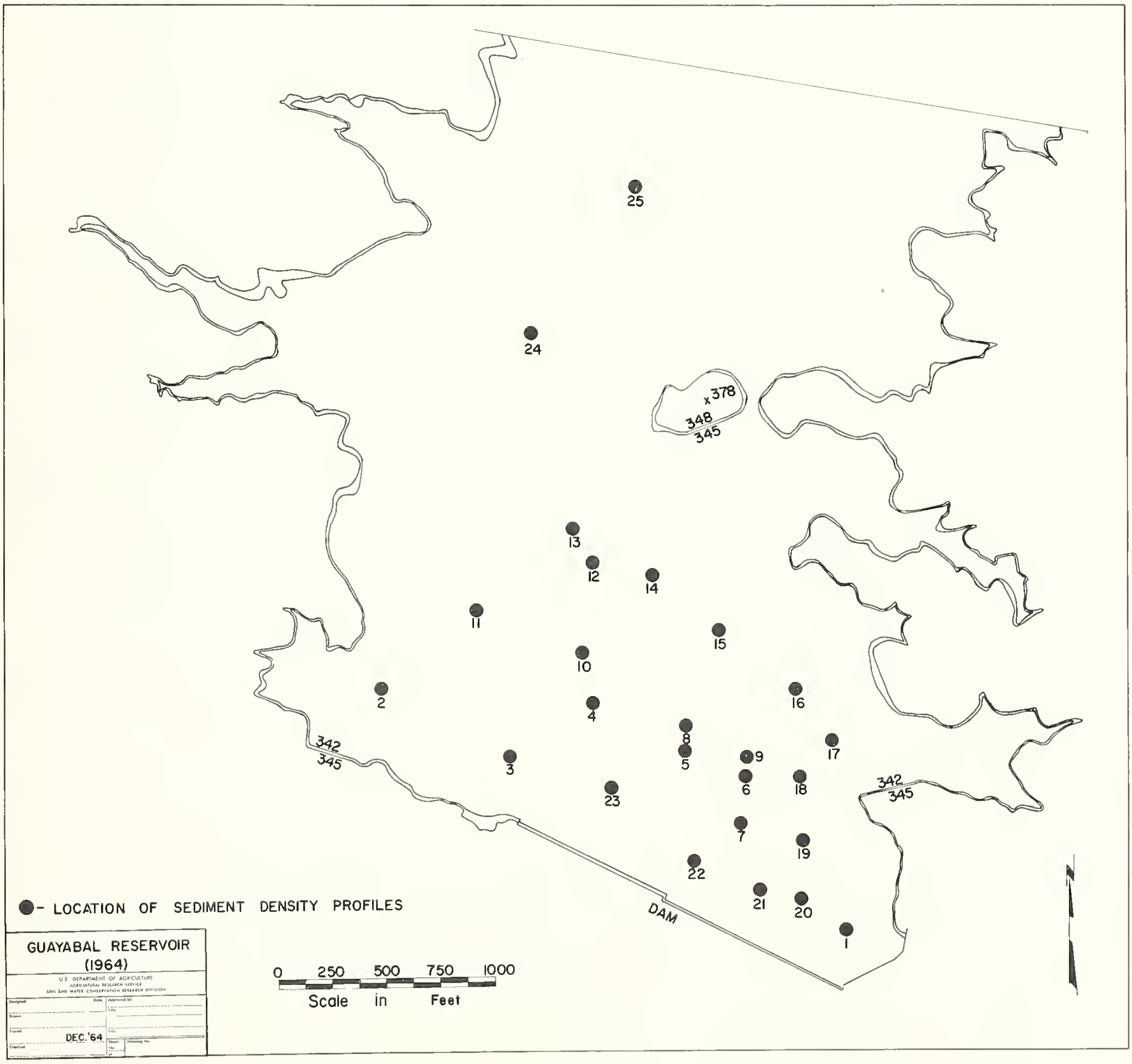


Figure 12.--Outline map of Lake Guayabal showing location of sediment density profiles measured with the gamma probe in October 1964.

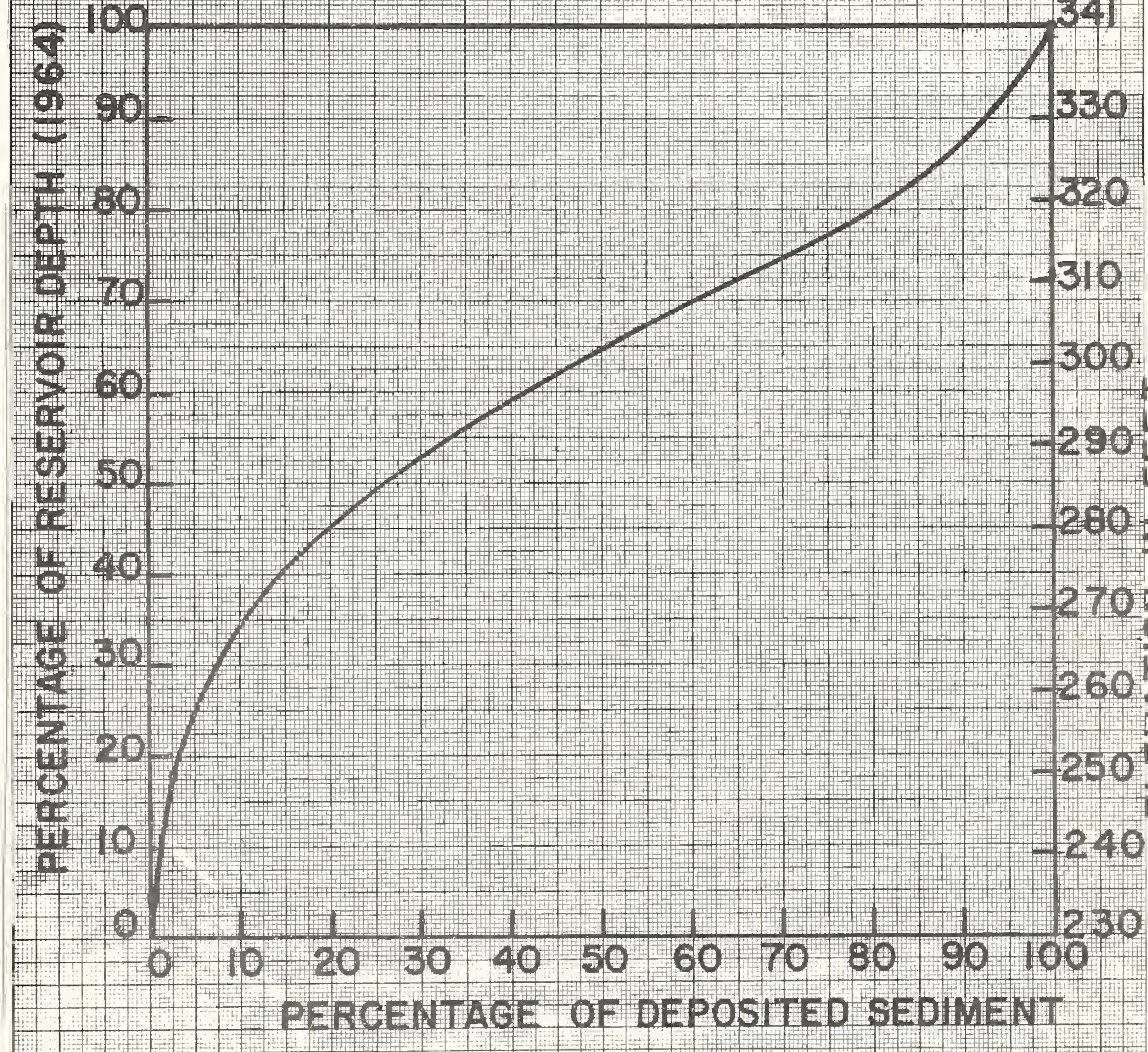


Figure 13.-The percentage of deposited sediment in Lake Guayabal plotted as a function of reservoir depth, 1964 survey.

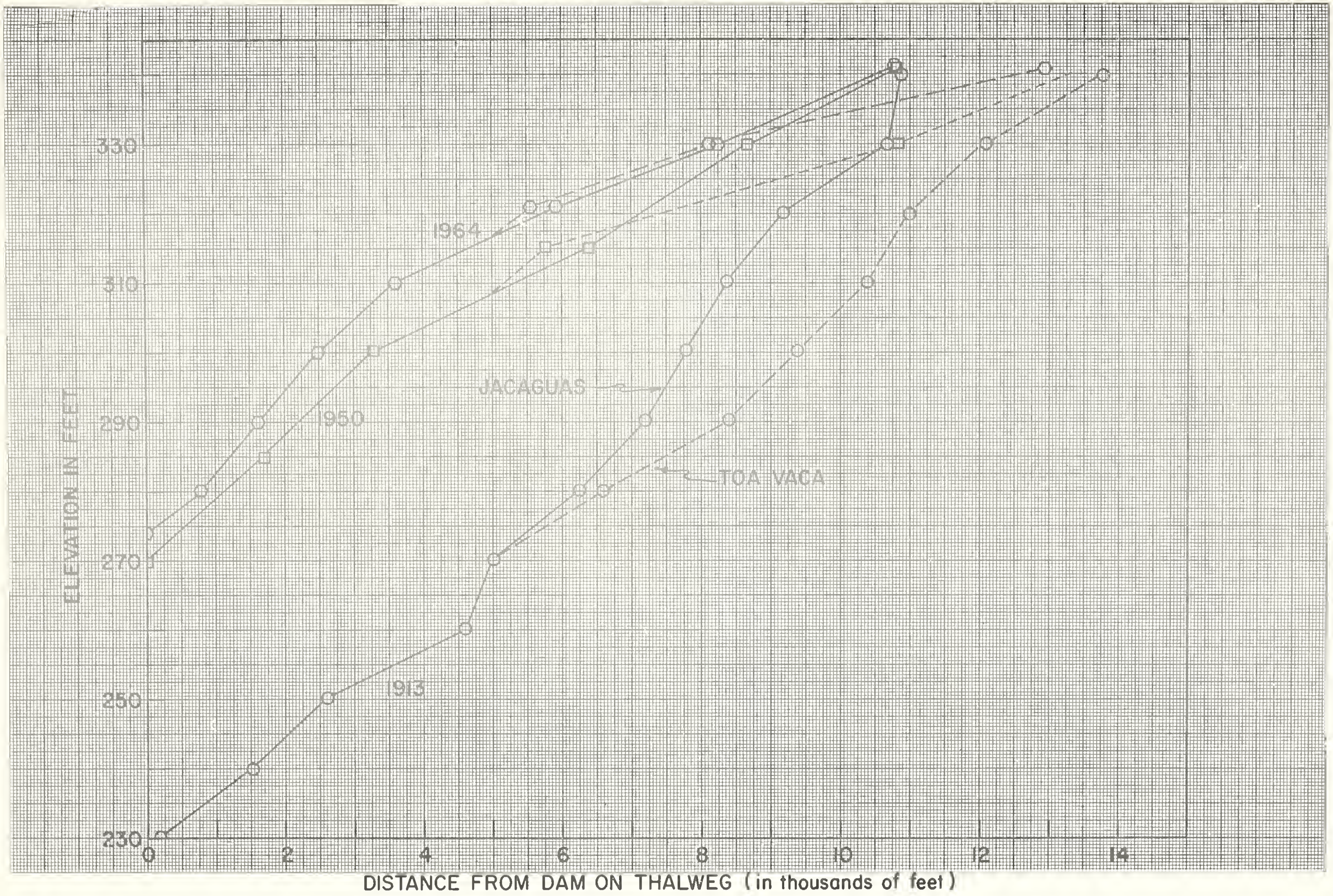
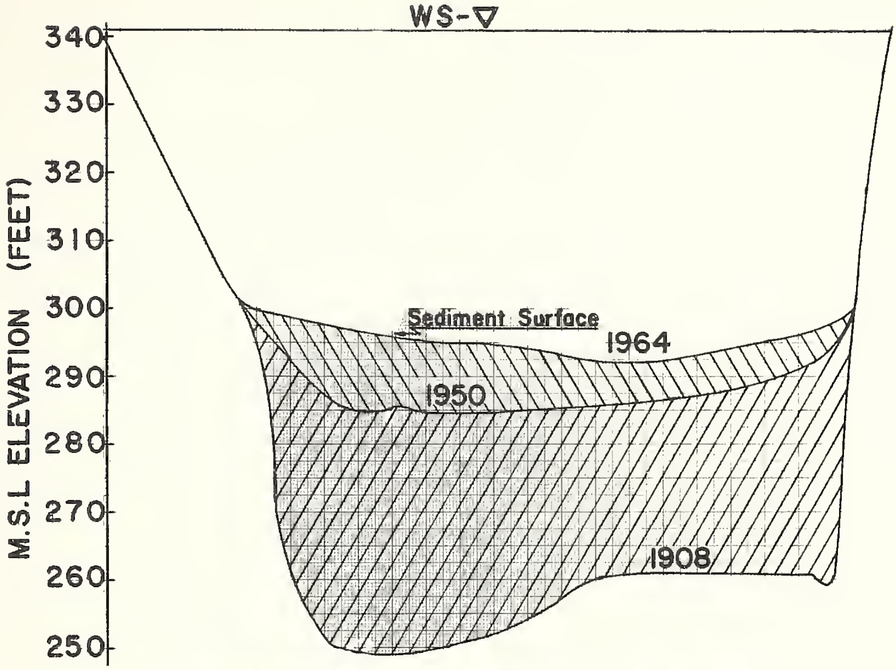


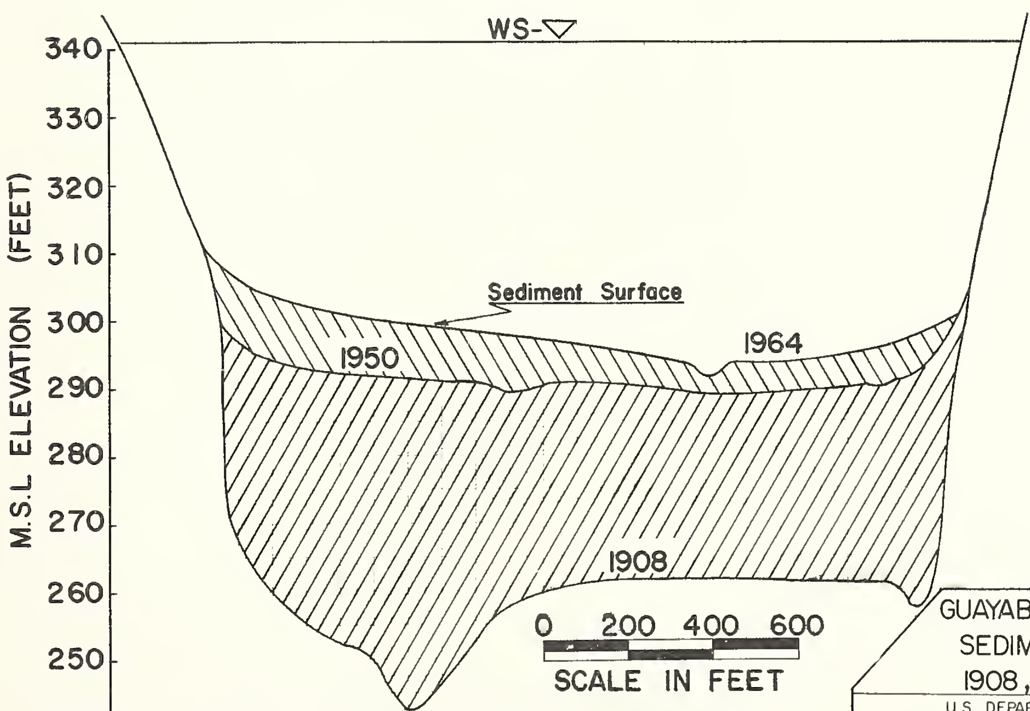
Figure 14.--The elevation, in feet, of the surface of the deposited sediment as a function of the distance from the dam along the thalweg. Data from 1908, 1950, and 1964 surveys are plotted for both the Toa Vaca and Jacaguas Rivers.

Figure 15a.--Selected cross-sections of sediment profile, Lake Guayabal, showing accumulations from 1908 to 1950, and to 1964. (Distances are measured directly north from dam; not along thalweg.)



Cross-Section "A" Located 200 Ft. North of Dam
Range N 60° E

0 200 400 600
SCALE IN FEET



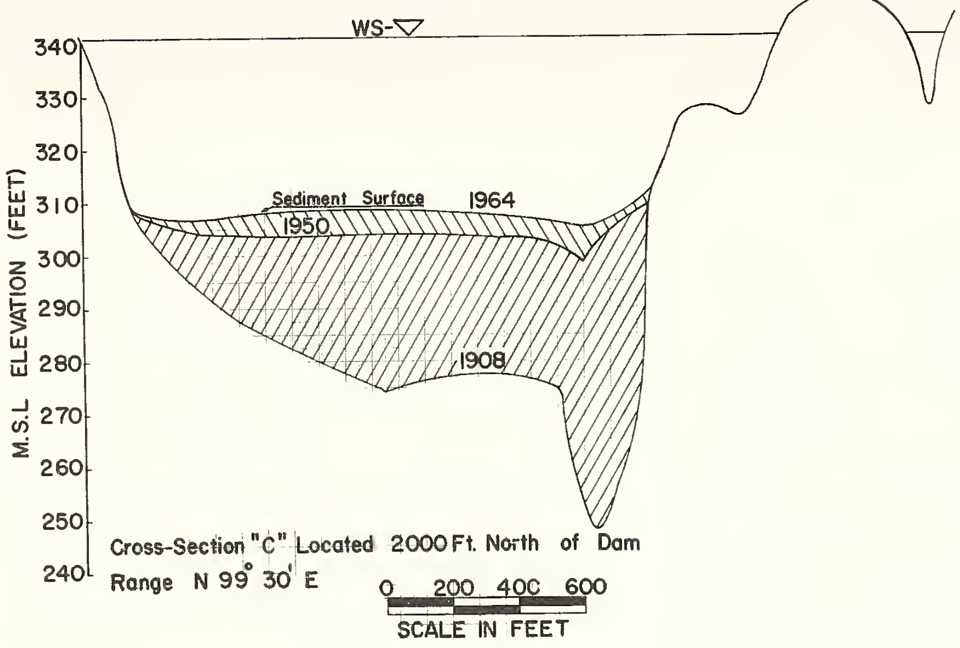
Cross-Section "B" Located 500 Ft. North of Dam
Range N 71° E

GUAYABAL RESERVOIR
SEDIMENT SURVEY
1908, 1950 & 1964

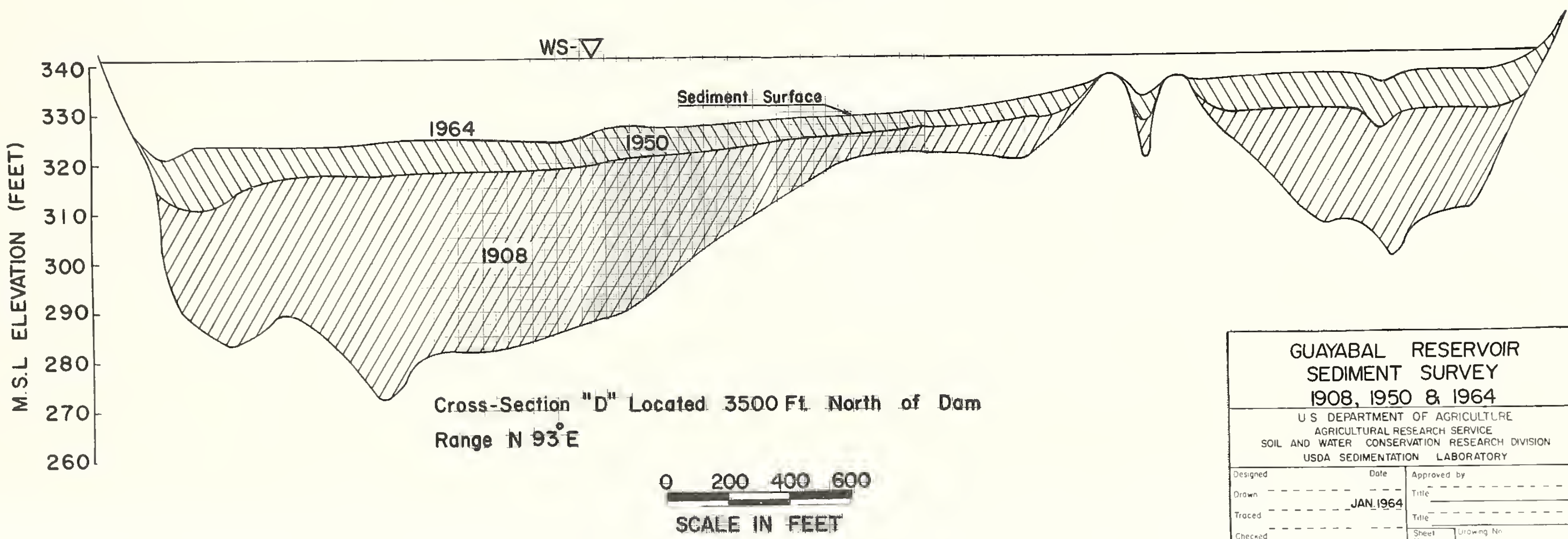
U.S DEPARTMENT OF AGRICULTURE
AGRICULTURAL RESEARCH SERVICE
SOIL AND WATER CONSERVATION RESEARCH DIVISION
USDA SEDIMENTATION LABORATORY

Designed	Date	Approved by
Drawn	JAN.1965	Title

Figure 15b.--Selected cross-sections of sediment profile, Lake Guayabal, showing accumulations from 1908 to 1950, and to 1964. (Distances are measured directly north from dam; not along thalweg.)



Cross-Section "C" Located 2000 Ft. North of Dam
Range N 99° 30' E



Cross-Section "D" Located 3500 Ft. North of Dam
Range N 93° E

GUAYABAL RESERVOIR
SEDIMENT SURVEY
1908, 1950 & 1964

U S DEPARTMENT OF AGRICULTURE
AGRICULTURAL RESEARCH SERVICE
SOIL AND WATER CONSERVATION RESEARCH DIVISION
USDA SEDIMENTATION LABORATORY

Designed	Date	Approved by
Drawn	JAN. 1964	Title
Traced		Title
Checked		Sheet No of / Drawing No

Figure 16.--Outline map of Lake Guayabal showing contour lines, 1964 survey, location of sediment density profiles, location of mechanical analysis samples, sonar ranges, and approximate course of thalweg.


N - LOCATION OF MECHANICAL ANALYSES SAMPLES
Rn — Rm RANGES FOR SONAR DEPTH SOUNDINGS
ⓝ — LOCATION OF SEDIMENT DENSITY PROFILES
X — — X THALWEG
0 250 500 750 1000
SCALE IN FEET
GUAYABAL RESERVOIR
1964 SURVEY
U.S. DEPARTMENT OF AGRICULTURE
AGRICULTURAL RESEARCH SERVICE
SOIL AND WATER CONSERVATION RESEARCH DIVISION
DESIGNED
DATE
APPROVED BY
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1964
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